Original Research

Psychological and Neuromechanical Recovery After Concussion: Dual-Task Stability and Kinesiophobia from Return to Play to Six Months

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Background

Sport-related concussion (SRC) increases the risk of subsequent musculoskeletal injury, yet the mechanisms underlying this vulnerability remain unclear. Fear of movement (kinesiophobia) may contribute to impaired motor control.

Purpose

This study examined kinesiophobia and postural stability in adolescent athletes at return-to-play (RTP) after SRC and evaluated changes six months later.

Design

Observational analytical study with cross-sectional (case-control) and prospective cohort components.

Methods

Thirty-seven concussed athletes (15.7 ± 1.3 years, 45.9% female) and 17 matched controls (16.4 ± 2.1 years, 52.9% female) completed static single-leg stance and dynamic single-leg landing tasks under single- and dual-task (Stroop) conditions. Fear of movement was measured with the Tampa Scale for Kinesiophobia (TSK-11). A subset of 12 concussed athletes and eight controls repeated testing at six months. Postural stability was quantified using ground reaction forces; higher values indicated worse performance. Group differences at RTP were examined using independent-samples t-tests or Mann-Whitney U tests. Longitudinal changes from were examined using paired-samples t-tests or Wilcoxon signed-rank tests. Effect sizes and exact p-values were reported, with α set at .05.

Results

At RTP, concussed athletes reported higher TSK-11 scores than controls (18.6 ± 4.2 vs. 15.6 ± 3.9, $p = 0.013$, $d = 0.74$). No significant group differences were observed for static or dynamic postural stability under single- or dual-task conditions (all $p > 0.12$). Within the concussion group, those with higher TSK-11 scores consistently showed poorer stability, although this difference was not statistically significant. At six months,

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concussed athletes demonstrated moderate improvements in TSK-11 (17.0 ± 3.9 to 13.4 ± 6.9) and dual-task dynamic stability, but changes did not reach statistical significance.

Conclusions

Adolescents cleared for RTP after SRC exhibited elevated kinesiophobia, despite having balance performance comparable to controls. Screening for fear of movement may help identify athletes at risk for delayed recovery or reinjury, complementing standard postural stability assessments.

Level of Evidence

3

INTRODUCTION

Sport-related concussion (SRC) symptoms generally resolve within 7-10 days, with approximately 80% of collegiate athletes meeting clinical return-to-play (RTP) criteria within two weeks.[1] Yet, these individuals face a twofold increase in subsequent lower extremity injury and concussion risk in the months following RTP.[2] Although impairments in reaction time, neuromuscular control, and sensorimotor integration have been implicated in this elevated risk, they do not fully explain the observed injury incidence.[3-11] In addition to these neuromotor deficits, recent work suggests that psychological responses to concussion, such as kinesiophobia, may further exacerbate post-SRC vulnerability.[12-14]

Kinesiophobia, which is defined as an excessive and debilitating fear of movement or reinjury,[15] has been extensively studied in musculoskeletal rehabilitation settings. Yet, its role in concussion recovery is less understood. Elevated kinesiophobia may directly influence neuromotor control by promoting protective movement strategies. Specifically, fear of reinjury has been shown to lead to increased muscle co-contraction around the knee and ankle, which reduces joint compliance.[16,17] In concussion cohorts, the Tampa Scale of Kinesiophobia (TSK) has demonstrated high reliability, and elevated scores within days of injury predict prolonged clinical recovery.[18,19] For example, collegiate athletes reporting high kinesiophobia acutely post-SRC require, on average, 2.5 days longer to RTP than those categorized as having low kinesiophobia.[19] However, these observations are confined to acute assessments and do not address whether sustained movement fear perpetuates sensorimotor deficits or increases subsequent injury susceptibility.

Dual-task paradigms that combine a cognitive interference challenge (e.g., Stroop task) with gait or balance assessments have revealed persistent sensorimotor deficits in concussed populations.[20-23] In a prospective study of concussed adolescents, dual-task gait revealed significant impairments in walking speed, anterior center of mass velocity, and medial-lateral sway persisting up to two months post-SRC.[24] Conversely, a larger cross-sectional sample of 128 adolescents showed no clear relationship between acute TSK scores and dual-task gait or balance error outcomes at roughly ten days post-concussion, despite nearly 30 percent reporting clinically significant fear of movement.[14] Together, these findings suggest that traditional dual-task gait and static balance measures may miss subtle but potentially important impairments linked to fear of movement. To address this, more sensitive dynamic stability measures are needed. The Dynamic Postural Stability Index (DPSI), which quantifies post-single-leg-hop landing stability in three planes, offers a more challenging and sport-specific assessment of neuromotor control under cognitive control.

The current study had two primary aims. First, this study examined kinesiophobia and postural stability in adolescent athletes at RTP after SRC compared with age- and sport-matched uninjured athletes. It was hypothesized that at RTP, concussed athletes would demonstrate greater dual-task instability than the controls, and the high-fear subgroup would perform worse than the low-fear subgroup. Second, this study evaluated changes in kinesiophobia and postural stability in concussed athletes six months later. It was hypothesized that both measures would converge toward control values over that time interval. Results from this study could provide clinicians with evidence and a corresponding rationale to incorporate brief kinesiophobia screening and dual-task balance assessments into RTP protocols, thereby improving identification of athletes at risk for delayed recovery or subsequent injury.

METHODS

The current study was an observational case-control study with a 6-month longitudinal follow-up. This study was approved by the Institutional Review Board at Duke University (Pro0081148). All participants provided written informed consent before participation.

PARTICIPANTS

For Aim 1, 37 concussed athletes (45.9% female) and 17 uninjured controls (52.9% female) completed testing. Exclusion criteria included having a history of three or more concussions or a lower-extremity injury that caused more than one day of time loss from sport. For Aim 2, a convenience subset of 12 concussed athletes (41.7% female) and eight controls (50.0% female) returned six months later.

EXPERIMENTAL INSTRUMENTATION

Ground reaction forces were collected via a single force plate (AMTI, Watertown, MA) at 1200 Hz for all postural stability tests. Visual stimuli were presented on an 80-inch high-resolution monitor (NEC, Irving, TX) positioned at eye level to maintain consistent visual engagement across tasks.

EXPERIMENTAL PROTOCOL

All testing was conducted in the human performance laboratory under single-task (motor only) and dual-task (motor and cognitive) conditions. Dual-task trials incorporated a visual Stroop task to impose cognitive load during balance testing. Participants were shown color words (e.g., “blue”) displayed in incongruent font colors and instructed to verbally identify the written word, not the font color. This paradigm creates cognitive interference and has demonstrated reliability in previous studies.[25] Trial accuracy was not considered because the primary objective was to apply a standardized cognitive load rather than evaluate individual cognitive differences. A one-minute seated rest was provided following every five trials to minimize fatigue. This protocol has demonstrated strong test-retest reliability for dynamic postural stability metrics across all movement directions (ICC = 0.71 – 0.94).[25] All assessments were administered by trained study personnel following a standardized protocol to ensure consistency across participants.

STATIC POSTURAL STABILITY TESTING

Static balance testing was performed barefoot under three conditions: 1. Eyes open, 2. Eyes closed, and 3. Eyes open with the Stroop task. During testing, participants stood on their self-reported dominant leg with the non-dominant foot placed along the midshaft of the opposite tibia, hands on hips, and eyes directed forward. They were instructed to maintain balance without flexing the stance leg, moving the foot, or contacting the raised limb. Touchdowns were permitted only if the non-dominant foot remained within the boundaries of the force plate; trials with external touchdowns were discarded and repeated. Each participant completed three trials per condition (9 total trials), with each trial lasting 10 seconds.

DYNAMIC POSTURAL STABILITY

Dynamic postural stability was assessed using a single-leg landing task performed under both single-task and dual-task (i.e., Stroop task) conditions. Participants began each trial by standing at a distance equal to 40% of their respective height from the designated landing zone. A 12-inch hurdle was placed at the midpoint (20% of participant height) between the starting point and landing zone. From this position, participants jumped off both feet over the hurdle and landed on their dominant leg. Upon landing, they were instructed to immediately adopt the static balance position, hands on hips, non-dominant foot placed along the midshaft of the stance leg tibia, and maintain it for 10 seconds. Any trial involving a touchdown or deviation from the balance position was excluded and repeated.

Single-Task Condition: Participants performed five valid trials of the landing task without any cognitive load. A minimum of three and a maximum of six practice trials were allowed immediately prior to data collection to ensure task familiarity.

Dual-Task Condition: For the dual-task condition, the Stroop task was integrated into the landing sequence. Participants completed three Stroop task trials before initiating the jump. Immediately after landing, they resumed the Stroop task and continued responding for the 10-second balance period. One to three practice trials were permitted immediately before test trials began. As with the single-task condition, five valid dual-task trials were collected.

KINESIOPHOBIA MEASURE

The Tampa Scale for Kinesiophobia (TSK-11) is an 11-item self-report measure used to assess fear of movement and reinjury.[15] Each item is rated on a 4-point Likert scale (1 = “strongly disagree” to 4 = “strongly agree”), with total scores ranging from 11 (low) to 44 (high). Initially developed for individuals with low back pain, the TSK-11 has demonstrated strong reliability and validity across various clinical populations. The TSK-11 has shown good internal consistency (α = 0.79), test-retest reliability (ICC = 0.81), and responsiveness (SRM = −1.11).[26] A cutoff score of ⩾25 was used to indicate high kinesiophobia.[27] Consistent with prior studies, a modified version was administered to participants in the concussion group, referencing their most recent concussion.[18] Control participants completed the scale in the context of any prior injury.

DATA PROCESSING

Force plate data were filtered using a 12 Hz low-pass Butterworth filter, exported, and processed with a custom MATLAB script. For static postural stability, the standard deviation of the ground reaction forces in the anterior/posterior, medial/lateral, and vertical directions was measured over each 10-second trial. Three trials were averaged for the final analysis with a higher score indicating worse postural stability. The primary variable for dynamic postural stability testing was the dynamic postural stability index (DPSI) (Figure 1). The DPSI is a composite of anterior/posterior, medial/lateral, and vertical ground forces. It was calculated using the first three seconds of the ground reaction forces following initial contact after landing during the jumping tasks. Similar to the static postural stability task, a higher DPSI signifies worse postural stability. Three trials were averaged for dynamic postural stability testing to be used for statistical analysis.

STATISTICAL ANALYSIS

Descriptive statistics (mean ± SD or median [IQR] for non-normal data) and assumption checks (Shapiro–Wilk and Q–Q plots for normality; Levene’s test for homogeneity of variances) were conducted for all variables. Variables that violated normality were analyzed with nonparametric methods.

To test Aim 1, independent-samples t-tests (with Welch’s correction when Levene’s test was significant) were used for normally distributed outcomes, and Mann–Whit-

$$\text{normalized DPSI} = \left(\sqrt{\frac{\Sigma(0\text{-GRFx})^2 + \Sigma(0\text{-GRFy})^2 + \Sigma(\text{body weight-GRFz})^2}{\text{number of data points}}} \right) \div \text{body weight}$$

Figure 1. Dynamic Postural Stability Index (DPSI) Calculation

Table 1. Participant Demographics Based on Test Timepoint, presented as mean ± standard deviation or number (%).

	RTP		RTP + 6 months	
	Concussed (N=37)	Control (N=17)	Concussed (N=12)	Control (N=8)
Age (years)	15.7±1.3	16.4±2.1	16.1±2.2	16.5±1.8
Height (cm)	171.1±9.3	170.1±8.5	169.3±8.0	170.3±6.9
Mass (kg)	65.4±13.6	66.0±10.8	66.0±10.8	65.6±9.7
Sex	N (%)	N (%)	N (%)	N(%)
Female	17 (45.9)	9 (52.9)	5 (41.7)	4 (50.0)
Male	20 (54.1)	8 (47.1)	7 (58.3)	4 (50.0)

RTP= return to play

ney U tests for skewed outcomes. Concussed athletes were further stratified into Low (TSK-11 < 25) and High (TSK-11 $\geq$ 25) fear-of-movement subgroups, and between-group differences in postural stability indices were examined with independent-samples t-tests or Mann–Whitney U tests as appropriate. Effect sizes for t-tests (Cohen's d) and non-parametric tests (Pearson's r) are reported, along with exact p-values.[28,29] Cohen's d was interpreted as small (0.20), medium (0.50), or large (0.80), and Pearson's r was interpreted as small (0.10), medium (0.30), or large (0.50).

To test Aim 2, paired-samples t-tests were applied to normally distributed measures and Wilcoxon signed-rank tests to non-normal measures. Within-subject effect sizes (dz for t-tests; r for Wilcoxon) and exact p-values are provided.[29] Effect sizes were interpreted using conventional thresholds, with dz values of 0.20, 0.50, and 0.80 representing small, medium, and large effects, respectively, and r values of 0.10, 0.30, and 0.50 representing small, medium, and large effects, respectively. All analyses were performed in SPSS Version 28 (IBM Corp., 2021) with $\alpha = .05$.

RESULTS

Demographic details by group and time point are shown in Table 1. The mean interval from concussion diagnosis to RTP testing was 41.7 ± 18.5 days.

PERFORMANCE AT RETURN TO PLAY

FEAR OF MOVEMENT AT RTP

Concussed athletes reported higher fear of movement than controls at RTP (t(54,2) = 2.62, p = 0.013), with a mean difference of 3.02 points between groups.

POSTURAL STABILITY AT RTP

Means, standard deviations, and medians for postural stability testing and TSK-11 scores are shown in Table 2. Single-leg eyes-open postural stability, single-leg eyes-closed postural stability, and single-leg dual-task postural stability showed data that were not normally distributed. Whereas the dynamic postural stability index and the dynamic dual-task postural stability index were found to have normally distributed data. No statistically significant differences were found between the concussed and control group means for postural or dynamic stability indices.

No significant difference existed in composite DPSI between concussed athletes and controls at RTP (U = 369, p = 0.639), suggesting similar dual-task postural stability between groups at the initial timepoint despite non-normal data distribution. Discuss effect sizes, please

TSK- 11 LOW VERSUS HIGH CONCUSSED GROUP

No statistically significant differences were found between the low and high TSK-11 subgroups on any postural stability measure (Table 3). However, the high-TSK group demonstrated directionally worse performance across postural stability indices, suggesting that fear of movement may be associated with subtle balance differences that were not statistically significant in this sample.

PERFORMANCE AT SIX-MONTH FOLLOW-UP

Scores for the TSK-11 decreased from 17.00±3.92 at RTP to 13.36±6.85 at follow-up. Although this change was not statistically significant, it demonstrated a moderate effect size (d = 0.53), suggesting a meaningful psychological improvement over time. Similarly, dynamic postural stability under dual-task conditions showed improvement, with the

Table 2. Concussed and Control Group Postural Stability Data at RTP.

	Concussion N=36		Control N=18			
	Mean±SD	Median	Mean±SD	Median	p - value	Effect Size
Single-Leg Eyes Open Postural Stability	11.91±4.20	11.22	10.72±4.11	9.81	0.296[a]	r=0.14
Single-Leg Eyes Closed Postural Stability	23.63±7.31	21.91	21.31±9.70	18.63	0.128[a]	r=0.21
Single-Leg Dual-Task Postural Stability	12.04±3.52	11.83	10.93±4.22	10.41	0.287[a]	r=0.14
Dynamic Postural Stability Index	0.35±0.04	0.37	0.36±0.04	0.36	0.716[b]	d=0.25
Dynamic Dual-Task Postural Stability Index	0.36±0.04	0.37	0.37±0.04	0.36	0.852[b]	d=0.25
TSK-11	18.58±4.16	18.00	15.56±3.91	15.00	0.013[b]	d=0.74

[a] p-value based on Wilcoxon rank-sum test. [b] p-value based on t-test.

Table 3. Concussed TSK- 11 Low and High Group Postural Stability Data at RTP.

	Low TSK-11 N=12		High TSK-11 N=24			
	Mean±SD	Median	Mean±SD	Median	p - value	Effect Size
Single-Leg Eyes Open Postural Stability	11.15±3.65	10.95	12.18±4.61	10.97	0.506[a]	r=0.02
Single-Leg Eyes Closed Postural Stability	20.57±5.92	21.62	25.19±7.73	20.34	0.078[a]	r=0.27
Single-Leg Dual-Task Postural Stability	10.69±2.99	11.65	12.53±3.67	10.92	0.142[a]	r=0.08
Dynamic Postural Stability Index	0.36±0.03	0.37	0.37±0.04	0.36	0.539[b]	d=0.27
Dynamic Dual-Task Postural Stability Index	0.36±0.04	0.36	0.37±0.04	0.36	0.541[b]	d=0.25

TSK= Tampa Scale of Kinesiophobia, RTP= return to play
[a] –p-value based on Wilcoxon rank-sum test. [b] p-value based on t test

Table 4. Comparison between RTP and RTP+6 months for the Concussion group

	RTP N=12		RTP+6 months N=12			
	Mean±SD	Median	Mean±SD	Median	p - value	Effect Size
Single-Leg Eyes Open Postural Stability Index	11.05±3.23	10.30	10.21±3.10	10.21	0.945[a]	r=0.02
Single-Leg Eyes Closed Postural Stability Index	20.47±5.78	19.99	17.67±6.02	17.67	0.625[a]	r=0.14
Single-Leg Dual-Task Postural Stability Index	11.26±3.24	10.21	8.47±3.10	8.47	0.232[a]	r=0.35
Dynamic Postural Stability Index	0.37±0.04	0.37	0.45±0.06	0.36	0.418[b]	d=0.24
Dynamic Dual-Task Postural Stability Index	0.37±0.03	0.37	0.33±0.04	0.36	0.087[b]	d=0.54
TSK-11	17.00±3.92	16.00	13.36±6.85	15.00	0.106[b]	d=0.53

RTP= return to play
[a] –p-value based on Wilcoxon rank-sum test. [b] p-value based on t test

DPSI decreasing from 0.37±0.03 to 0.33±0.04, indicating enhanced performance (p =0.087, d = 0.54). No significant changes were observed in static postural stability measures (Table 4).

DISCUSSION

This study investigated the relationship between kinesiophobia and postural stability in adolescent athletes recently cleared to RTP following SRC. Consistent with the hypothesis, concussed athletes reported significantly higher fear of movement at RTP compared to matched controls. However, contrary to expectations, no significant differences were observed between groups in static or dynamic postural stability under either single- or dual-task conditions. Clinically, this suggests that standard balance tests alone may fail to capture lingering neuromechanical deficits linked to kinesiophobia. Practitioners can integrate brief fear of movement screenings (e.g., TSK-11) into RTP protocols to identify athletes who might benefit from targeted cognitive-behavioral or graded-exposure interventions, even if their objective balance appears restored. Future research should evaluate whether early psychological support accelerates neuromotor recovery and reduces the risk of subsequent injury and explore more sensitive movement-based assessments that combine cognitive load with sport-specific tasks.

The present results align with prior research demonstrating elevated kinesiophobia in concussed athletes during the acute and subacute phases of recovery.[18,19] The observed mean difference in TSK-11 scores between concussed and control groups (d = 0.74) represents a moderate-to-large effect, reinforcing that fear of movement is a salient psychological response to concussion. However, unlike studies that have reported persistent dual-task gait impairments up to two months post-injury,[22,23] the present findings did not reveal significant postural stability deficits at RTP. This discrepancy may be due to differences in task demands, the timing of the assessment, or the compensatory strategies employed by athletes.

Specifically, the use of a single-leg landing task with a Stroop interference paradigm may have elicited different neuromechanical responses than gait-based dual-task assessments. While gait tasks often reveal deficits in stride variability and center of mass control, the force plate-based metrics used in the present study may be less sensitive to subtle compensation. It is also possible that athletes employed protective neuromuscular strategies, such as increased co-contraction of agonist-antagonist muscle groups, to maintain postural control under cognitive load. This hypothesis is supported by findings in musculoskeletal populations, where fear of reinjury has been linked to increased joint stiffness and altered muscle activation patterns.[16,17] However, joint stiffness and muscle activation were not measured in the present study, so this explanation remains speculative. Such strategies may mask underlying deficits, particularly in well-practiced or low-complexity tasks.

Although postural stability did not differ significantly between the high and low kinesiophobia subgroups, the high-fear group consistently demonstrated worse performance across all metrics. This pattern mirrors findings from anterior cruciate ligament reconstruction cohorts where elevated fear of reinjury is associated with poorer single-leg hop performance and delayed functional recovery.[17,30] These results suggest that similar psychological mechanisms may be at play in concussion recovery, potentially contributing to the elevated risk of subsequent musculoskeletal injury observed in this population.[2]

At six-month follow-up, concussed athletes showed moderate improvements in both TSK-11 scores and dual-task dynamic postural stability, although these changes did not reach a statisticallysignificant difference. The moderate effect sizes for TSK-11 (d = 0.53) and dynamic dual-task postural stability (d = 0.54) suggest that reductions in kinesiophobia and improvements in dual-task postural control may have occurred over time, despite nonsignificant p-values. These trends may reflect gradual neuromechanical recovery and psychological adaptation over time. However, the small follow-up sample limits the generalizability of these findings. Future studies with larger longitudinal cohorts across a broader age range are necessary to clarify the temporal relationship between fear of movement and sensorimotor function after a concussion.

CLINICAL TRANSLATION

Clinically, these findings underscore the importance of incorporating psychological assessments into RTP protocols. Current guidelines emphasize symptom resolution and basic balance testing,[31] but may overlook athletes who are psychologically unready to resume sport. Routine screening for kinesiophobia using brief, validated tools like the TSK-11 could help identify individuals at elevated risk for reinjury. Moreover, interventions targeting fear of movement, such as graded exposure or cognitive-behavioral therapy, may enhance both psychological and physical recovery. Although the present study utilized force plate-based measures to quantify postural stability, the underlying constructs are clinically translatable. Dual-task balance challenges can be implemented using feasible approaches, such as single-leg stance tasks combined with cognitive interference (e.g., Stroop or verbal tasks), allowing clinicians to assess sensorimotor performance without laboratory instrumentation.

LIMITATIONS

The six-month follow-up sample was small and may be subject to selection bias. The average testing interval from injury to RTP assessment may reflect variability in recovery timelines and participant availability. This could introduce sampling bias, as athletes tested at later stages of recovery may differ from those assessed earlier, potentially limiting internal validity and generalizability. Additionally, this variability in testing timing may reflect differences in recovery trajectory and clinical clearance, which could further influence observed outcomes. Second, whereas the TSK-11 has demonstrated reliability in musculoskeletal populations, its psychometric properties in concussion cohorts remain underexplored. Further, kinesiophobia was assessed via self-report and may be subject to recall and response bias. Third, the dual-task paradigm may not fully replicate the complex sensory and cognitive demands of sport, potentially limiting ecological validity. Relatedly, laboratory-based assessments may not fully capture performance in more ecologically valid or sport-specific environments, introducing potential measurement bias. Fourth, the present study's analytic approach excluded trials with touchdowns or large deviations, which may have inadvertently biased results toward participants' most stable performances. It is possible that instability in the concussion group manifested as touchdowns, and removing these trials reduced sensitivity to true between-group differences. In addition, unmeasured confounding variables, including prior injury history, rehabilitation exposure, and individual differences in recovery, may have influenced both kinesiophobia and postural stability, potentially affecting the observed relationships. Finally, the average testing interval (~82 days post-injury) may have missed earlier windows of instability, as prior studies have identified postural deficits within the first month post-concussion.[22]

Future research should employ multi-site, longitudinal designs that include pre-injury baselines, serial post-injury assessments, and return-to-sport outcomes. Incorporating electromyography could help quantify co-contraction patterns and clarify compensatory neuromuscular strategies. Additionally, randomized trials evaluating the efficacy of fear-targeted interventions on both psychological and biomechanical outcomes would provide critical evidence to inform comprehensive concussion management.

CONCLUSION

Athletes recently cleared for RTP following a concussion exhibit elevated kinesiophobia, yet traditional postural stability assessments may not detect subtle neuromechanical impairments during this phase. While no significant group differences were observed in balance performance, consistent trends suggest that fear of movement may subtly influence motor control. These findings underscore the importance of integrating psychological screening tools, such as the TSK-11, into RTP protocols. Future research should explore the utility of more sensitive biomechanical measures and evaluate the impact of fear-reduction strategies on long-term outcomes.

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CONFLICT OF INTEREST

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